CASE STUDIES OF SYSTEMS INTEGRATION THROUGH ENERGY SIMULATION DURING EARLY DESIGN PHASE

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ABSTRACT

The paper presents two case studies, a commercial & a community project, in Houston Texas, where energy simulation and a decision matrix were used to solve budget conflicts and meet LEED EA-1 requirements. The first case study consists of the analysis of three different direct-expansion (DX) systems in an underfloor air distribution (UFAD) configuration for an office building with an unusually large footprint. Of the three options, only two could meet EA-1 pre-requisite for LEED-NC certification while meeting the project budget. The second case study involves analysis of a 120,000 sf. community recreation center with multiple space types and operation schedules. The analysis employed different combinations of energy recovery systems, efficient lighting package, skylights and large efficient ceiling fans. While all the options met LEED-NC EA-1 prerequisite, each had a different payback time. Finally a combination of strategies was used for optimum payback and energy efficiency.

INTRODUCTION

Selecting the appropriate building design, in today's market of multiple best "Green" technologies, depends on early identification and integration of systems through a coordinated effort by the client, architect, engineer and contractor during the schematic design phase. It is the intent of this paper to show how the analysis tools and processes used, aided in the decision process.

CASE STUDY 1

The core and shell building consisted of three pods for office spaces in Houston, each of 112,500 sf. and three floors high, connected by lobbies on two floors; the first floor lobby was double height. Figure 1 shows the Equest image of the proposed building. The project goal was to achieve LEED-CS silver rating. At the end of schematic design (SD) phase when the architectural design was finalized, a decision on HVAC system was to be made incumbent upon the fact that the system selected should be able to meet the LEED prerequisite of 14% energy efficiency over ASHRAE 2004 baseline building.

For a building of this size, a chilled-water system would be a typical choice. While a chilled-water system could meet the 14% requirement in Houston, as demonstrated in Biesterveld[1] et al., there was a significant investment savings if DX units were selected. Additionally, there is research demystifying the dehumidification effectiveness of a chilled-water system over DX units; for example, Browning[2] discusses a method to estimate and hence effectively use dehumidification for comfort cooling with correct sizing of low cost DX equipment in hot and humid climates.

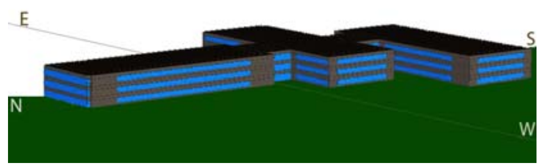


Figure 1. Equest image of office building.

Following these, three representative DX units were selected for performing energy analysis. The office areas were designed for underfloor air distribution while the lobbies were served by traditional mixed-ventilation system. A baseline energy model was built conforming to Appendix G, ASHRAE 2004. Table 1 shows the envelope design data used for the purpose. Table 2 shows envelope design data for the proposed building envelope.

Table 1. Envelope design data for baseline building.

	Specifications for Base Case according to ASHRAE 2004 Appendix-G		
	Building components	Assembly Max	Insulation Min. R-value
GROUND FLOOR / SLAB ON GRADE	Unheated Slab on Grade	NR	
INTERMEDIATE / INTERSTITIAL FLOORS	NR		
EXTERNAL WALL	Mass walls R-13 Batt insulation	U-0.124	R-13
INTERNAL WALL	NR		
ROOF	Insulation entirely above deck 3/8" Built Up Roofing R-19 Insulation Steel Frame 24"oc	U-0.063	R-19
	Reflectivity	0.3	
VERTICAL FENESTRATION		Assembly Max U-value	Assembly Max SHGC
	Vertical glazing 437.2% WWAR	1.22	SHGC - 0.17 SHGC(N) - 0.61
SKY-LIGHTS	None		
SHADING	None		

Table 2. Envelope design data for proposed building.

	Specifications for the Proposed Design Building		
	Building Envelope components used by simulation model		U-value
GROUND FLOOR / SLAB ON GRADE	9inch concrete unheated slab on Grade		NR
INTERMEDIATE / INTERSTITIAL FLOORS	NR		
EXTERNAL WALL	Mass Wall ; 10" Concrete Tilt Walls ; Internal Batt Insulation R-13		R-13 insulation
INTERNAL WALL	NR		
ROOF	Insulation entirely above deck ; R19 Thermoplastic Membrane Roofing 1 ½" Galvanized Sheet		R-19 insulation
	Reflectance 0.3		Reflectance 0.3
VERTICAL FENESTRATION		Assembly Max U-value	Assembly Max SHGC
	Type 1 Type 2	0.29; 0.29 Solarscreen VRE Insulating Glass Daylighting controls simulated in the the two lobbies only.	0.30; 0.30
SKY-LIGHTS	None		
SHADING	Shading per design / drawing (Overhangs on South and East)		

Table 3. Lighting design data for baseline building and proposed building

DOE-2.1E Command / Keyword	BASELINE BUILDING		PROPOSED BUILDING		Input Description
OFFICE SPACE	INPUT	SOURCE	INPUT	SOURCE	
LIGHTING-W/SQFT	1.1-office, 0.5-corridor, 1.5-elect. Room, 0.9-Restroom, 1.1-Lobby, 0.15-Exterior,1.1-Copy Rm.	From: ASHRAE 2004 Table 9.5.1 Pg 64	1.1-office, 0.5- corridor, 1.5-elect. Room, 0.9-Restroom, 1.1-Lobby, 0.15-Exterior,1.1-Copy Rm.	From: ASHRAE 2004 Table 9.5.1 Pg 64	W/SQFT

Table 4. HVAC design data for baseline building and proposed building.

		BASELINE BUILDING	PROPOSED BUILDING
HVAC System Definition	Cooling Source	Chilled Water Coils	DX Coils
	Heating Source	Electric Resistance	Electric Resistance
	System Type	Packaged VAV with PFP boxes	Packaged VAV Rooftop units with perimeter underfloor boxes
	System per Area	2 Systems per Floor	2 Systems per Floor
	Return Air Path	Plenum	Plenum
Seasonal Thermostat Set points	Occupied		
	Cool Heat	74 72	74 72
	Unoccupied		
	Cool Heat	74 72	74 72
Design Temperatures	Cooling Design Temp		
	Indoor Supply	74 54	74 63
	Heating Design Temp		
	Indoor Supply	72 92	72 85
Air Flows	Minimum Design Flow	0.40 cfm/sqft	0.65 cfm/sqft
	VAV Minimum Flow	30%	30%
Supply Fans	Power & Mtr Eff	2.4 in.WG for offices, 3.5 in. WG for lobbies; High efficiency	2.4 in.WG for offices, 3.5 in. WG for lobbies; High efficiency
HVAC ZONE HEATING, VENT & ECONOMIZERS	Fan Type	Variable Speed Drive	Variable Speed Drive
	Baseboards	None	None
Zone Heat Sources & Capacities	Heat/ Reheat Electric	30 F	30F

Condenser Type		Air Cooled	Air Cooled
Cooling	EER/COP	6.1 COP	**9.4 EER – System 1** **11.4 EER – System 2** **12.3 EER – System 3**
Heating	Zonal Heating and Reheating Only		Zonal Heating and Reheating Only

UNDERFLOOR SYSTEM IN EQUEST

Equest does not have algorithms to simulate air-flow and hence displaced ventilation systems. So a method suggested in HVAC Simulation Guidelines [3] was adopted which consists of distributing occupant, lighting and equipment power to the thermal zone and an overhead return plenum; this would approximately represent stratification of air and hence cooling load attributed to the thermal zone and return plenum. Table 4 shows a sample zone with the redistribution of power densities. Additionally, to account for latent cooling loads the coil-bypass factor was increased so as to simulate air leaving the coil at 53ºF while the mixed-air leaving the AHU at 65ºF.

Table 5. Distribution of power densities in baseline building and proposed building.

EL1(BASELINE)	Perimeter	Core	Perimeter	Core	Perimeter	Core
OPD	137	230	200	193	200	193
LPD	1.11	1.08	1.11	0.99	1.11	0.99
EPD	1.186	1.151	2	1.377	2	1.377
EL1(PROPOSED)						
OPD	183	307	267	257	267	257
LPD	0.74	0.72	0.74	0.66	0.74	0.66
EPD	0.79	0.77	1.34	0.92	1.34	0.92

OCCUPANT DENSITY FOR PLENUM:

SPACE	**AREA**	**O.P.D.**	**O.PD./AREA**	
EL1 West Perim Spc (G.W1)	1575	183	0.1162	2058
EL1 South Perim Spc (G.S2)	4529	183	0.0404	5919
EL1 East Perim Spc (G.E3)	1574	183	0.1162	2058
EL1 North Perim Spc (G.N4)	4380	183	0.0418	5724
EL1 Core Spc (G.C5)	25327	307	0.0121	33100
∑AREA PER PERSON/AREA OF SPACE			0.3267	
AREA OF PLENUM			37385	
AREA PER PERSON (PLENUM)			489	

LIGHTING POWER DENSITY FOR PLENUM:

L.P.D.	L.P.D.*AREA
0.74	1166
0.74	3352
0.74	1165
0.74	3241
0.72	18235

EQUIPMENT POWER DENSITY FOR PLENUM:

E.P.D.	E.P.D.*AREA
0.79	1244
0.79	3578
0.79	1244
0.79	3460
0.77	19502

∑AREA L.P.D.*AREA OF SPACE	27159	∑AREA E.P.D.*AREA OF SPACE	29028
AREA OF PLENUM	37385	AREA OF PLENUM	37385
LIGHTING POWER DENSITY(PLENUM)	0.24	EQUIPMENT POWER DENSITY(PLENUM)	0.26

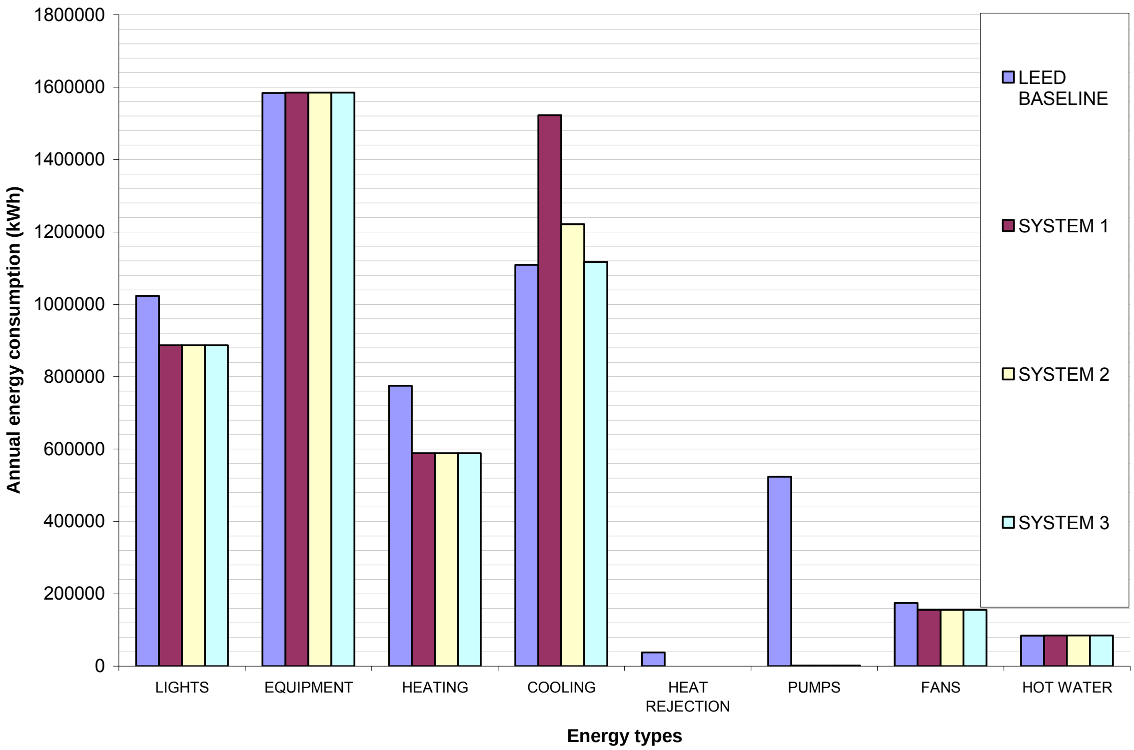


Figure 2. Comparison of annual energy types for all systems.

The annual cost of electricity for the baseline building at 10cents/kWh, was $584436 as compared to $530808 for System 1 (refer Table 4 for individual system description), $497659 for System 2, and $486211 for System 3. This corresponds to 9.18% for System 1, 14.85% for System 2, and 16.8% for System 3. Evidently, System 2 and System 3 would be able to meet the LEED prerequisite of 14%.

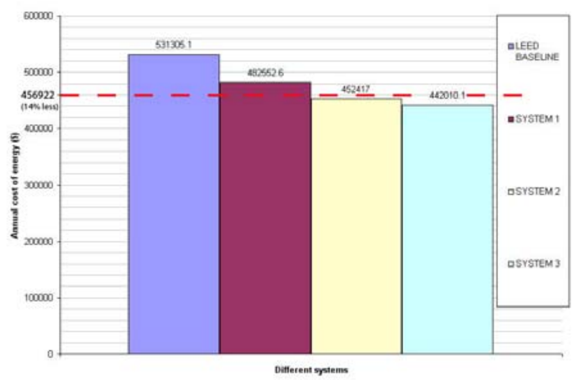


Figure 3. Comparison of annual cost of energy.

System 2 was finally selected for the project and later, in the value engineering phase, the same energy model was used to determine effects of changing glazing and shading devices.

CASE STUDY 2

The five floor community building consisted of children play areas and training rooms on first and second floors; swimming and therapy pools on the third floor; gym, workouts and running track on fourth and fifth floors.

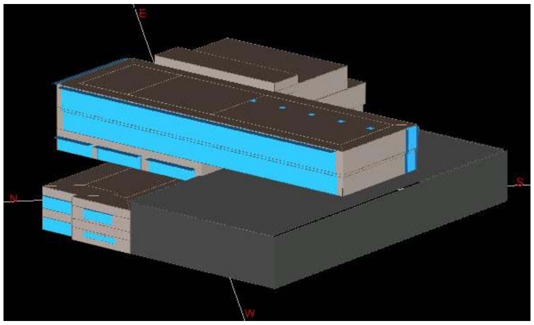


Figure 5. Equest image of community building.

The project goal was to look at all possible energy efficient strategies and estimate payback costs in the SD phase. A LEED-baseline-building energy-model was created per Appendix G, ASHRAE 2004; energy-recovery with heat pipe was implemented per code requirements. A proposed-building energy-model was created with chilled-water system and heat pipe for energy recovery. Table 5 lists the system description of the proposed building. Parametric variations of this were created with the following energy efficient features:

1. Big ceiling fans in all workout areas to reduce total static pressure in ducts by 1in. wg. & increase thermostats by 4°F. This was based on a study (James et al.) which estimates a reduction of 2-6°F in space temperatures with the use of ceiling fans. An external scheduled load was added to the energy model to represent the fan load.

2. Shading on the north-west with vertical fins to block direct sunlight and glare. Shading studies were carried in Ecotect to determine optimum depths and spacing.

3. Daylighting controls using stepped-dimming at perimeter to harvest daylight and save energy (30fc setpoint).

4. Efficient lighting package to include a 20% reduction in lighting power density over ASHRAE 2004 with stepped lighting controls.

5. Five skylights on the fifth floor to harvest daylight.

6. Solar hot water system for therapy pool.

7. Energy Recovery Unit (ERU) with desiccant wheel to treat outside air - Trane Energy Wheel S2500 H, 767,791btu/hr total capacity; Trane CDQ Dessicant Wheel - 137.6lb/hr water vapor transfer, - 199,058btu/hr heat transfer capacity.

Enthalpy Wheel type- recovering both sensible and latent heat; Operating mode - both heat/cool; Make up air temperature control- mixed Air Reset; Capacity Control- bypass OA; Operation-OA exhaust DT; OA/Exhaust DT- 5°F.

8. Systems 1-7 combined. This option combines of the above mentioned options from 1 to 7 in a single building.

9. Option 8 with reduction in chiller capacity by 40 ton. This was an approximate reduction in chiller capacity modeled with reduction in loads due to all the above strategies.

10. Option 9 with shading removed. This was done to compare payback time of all other strategies without the most expensive option of external shading device. Option 10 turned out to be the most cost-effective.

11. Option 10 with ceiling fans and efficient lighting removed.

Table 6. HVAC design data for the proposed community building.

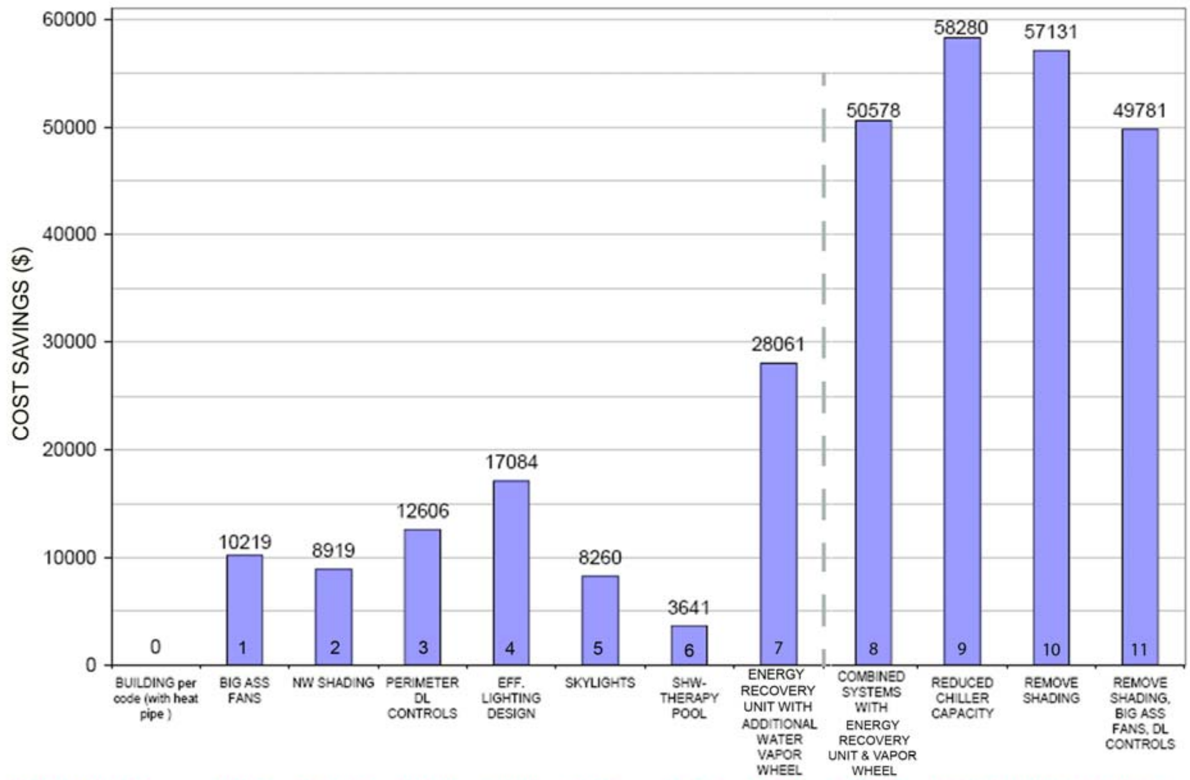
	SYSTEM TYPE 1 (floor 1)	SYSTEM TYPE 2 (floor2,4,5)	SYSTEM TYPE 3 (floor 3)
			Pool
Temperature	75 F Summer 72 F Winter	75 F Summer 72 F Winter	82 F Summer 82 F Winter
People-schedule	A	A	B
Area/person	150	50	300
People-heat gain-latent	200	625	500
People-heat gain-sensible	250	375	340
HVAC SYSTEM DESCRIPTION			
Equipment type	Chilled water coils with water cooled condensers		
Cooling Source	Chilled water coils	Chilled water coils	Chilled water coils
Heating Source	Electric resistance	Electric resistance	Electric resistance
System Type	Series powered VAV with elec. Reheat	Series powered VAV with elec. Reheat	Single Zone Air Handler with Elec. Heat
Return Air Path	Plenum	Plenum	Ducted
Occupied			
Cool	75	72	82
Heat	72	70	82
Unoccupied			
Cool	85	85	82
Heat	55	55	82
Design Temperatures			
Cooling Design Temp			
Indoor	75	75	82
Supply	56	56	60
Heating Design Temp			
Indoor	72	72	72
Supply	85 to 95	85 to 95	95
Air Flows			
Minimum Design Flow	0.75 cfm/sqft	0.75 cfm/sqft	1 cfm/sqft
VAV Minimum Flow	30% primary flow	30% primary flow	100% perimeter 100% core
HVAC SYSTEM FANS			
Supply Fans			
Power & Mtr Eff	3.5 in.WG, High	3.5 in.WG, High	3.5 in.WG, High
Fan Type	Variable Speed Drive	Variable Speed Drive	Constant Vol
Heat Reheat Electric	30F	30F	30F
CHILLED WATER SYSTEM			
Pump Configuration	Single system pumps, variable primary flow		
Number of System Pumps	1		
CHW Loop Flow	Constant speed		
Pump Control	VFD/VSD		

Loop Pump Motor Efficiency	Premium (93%)
Chiller Type	Electric Centrifugal Hermetic
Condenser Type	Water Cooled
Compressor Type	Constant Speed
Number & size	2, 200-400 TONS
Chiller Efficiency	0.50 kW/ton
WATER COOLED CONDENSOR / COOLING TOWER	
Condenser Configuration	Open Tower
Temperature Control	Fixed
Setpoint	86F
Capacity Control	variable speed fans
Chilled Water Setpoint Type	OA Reset
CHW Min Temp	42F
CHW Max Temp	58F
Operation	Stand-by

One shortcoming of the simulations was the inability to model thermal mass of pool-water. Another approximation lies in the inability of Equest to integrate a separate outside-ahu with each floor-ahu in Equest. To overcome this, dummy zones were created with ‘0’ loads; OAHUs were assigned to these with energy-recovery capacities per design. Each floor-ahu was then assigned to draw outside-air from these.

Figure 5 compares the annual cost savings due to the individual energy efficient strategies, the respective investment, payback time, cumulative income in twenty-five years and the LEED points earned by each option.

It could be seen that the proposed building was able to meet the LEED 2.2 pre-requisite of 14% with the chilled water system. Among individual strategies, skylights give the fastest payback followed by energy-recovery unit with vapor wheel. Efficient lighting, ceiling fans and perimeter daylight controls follow next. The external shading devices considered for this project remain unprofitable due to cost and orientation of the building. Combination of all the strategies without the shading device could achieve a payback of 3.1 years.



	0	1	2	3	4	5	6	7	8	9	10	11
INVESTMENT($)		54,000	335,000	78,788	39,447	7,889	18,500	33,000	576,624	520,424	195,424	62,636
PAYBACK (YEAR)		5.1	>25	6.1	2.2	0.0	5.0	1.2	10.0	8.0	3.1	3.3
CUMULATIVE INCOME ($ AFTER 25 YRS.)		265,629	0	302,591	501616	263,562	-	889,212	1,066,348	1,375,694	1,657,117	1,541,360
LEED EA CREDITS	2	3	2	3	3	2	2	4	5	6	6	5

Figure 5. Cost savings for different energy saving strategies.

CONCLUSIONS

Energy modeling done in the early design phase helps in making significant decisions during the design process like effects of changing glazing, shading devices, operation schedules and lighting/equipment efficiencies. It also helps in making decisions on HVAC systems and testing atypical technologies which need integration in buildings at the SD phase like energy recovery, skylights and daylighting controls. Simulations at this stage come with assumptions with regards to details of systems and sometimes architectural design, but are nevertheless useful.

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